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THESIS

OPTIMIZING THE MODERNIZATION OF EASTERN EUROPEAN FORCES

by

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Many Eastern European countries desire a method to evaluate the capability and cost of their military forces. In 1995 the Program Analysis and Evaluation branch of the Office of the Secretary of Defense (OSD PA&E) provided a solution: the Defense Resources Management Model (DRMM). The DRMM is a database system that contains detailed report writing, allowing a nation's military to be described by: how its forces are organized and equipped; how it staffs its forces; how it scales its peacetime training rates; and how it practices budgeting and accounting. We present a multi-objective linear program extension to the DRMM that suggests optimal yearly unit levels, activity, manning, equipment and war reserve materiel levels. Two objectives are used in the analysis: (1) We find the minimum budget required to maintain a given capability level; (2) We find the maximum capability within an annual budget. Possible uses of the linear programming extension are demonstrated using a hypothetical but realistic Eastern European force supplied by OSD PA&E. Results show the ability to maintain current capability but reduce annual spending by up to 30 percent. Other results show how capability can be increased nearly 50 percent over a five-year time horizon by increasing annual budget levels ten percent above their current levels.

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OPTIMIZING THE MODERNIZATION OF EASTERN EUROPEAN FORCES

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ABSTRACT

Many Eastern European countries desire a method to evaluate the capability and cost of their military forces. In 1995 the Program Analysis and Evaluation branch of the Office of the Secretary of Defense (OSD PA&E) provided a solution: the Defense Resources Management Model (DRMM). The DRMM is a database system that contains detailed report writing, allowing a nation's military posture to be described by: how its forces are organized and equipped; how it staffs its forces; how it scales its peacetime training rates; and how it practices budgeting and accounting. We present a multi-objective linear program extension to the DRMM that suggests optimal yearly unit levels, activity, manning, equipment, and war reserve materiel levels. Two objectives are used in the analysis: (1) We find the minimum budget required to maintain a given capability level; (2) We find the maximum capability within an annual budget. Possible uses of the linear programming extension are demonstrated using a hypothetical but realistic Eastern European force supplied by OSD PA&E. Results show the ability to maintain current capability but reduce annual spending by up to 30 percent. Other results show how capability can be increased nearly 50 percent over a five-year time horizon by increasing annual budget levels ten percent above their current levels.

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EXECUTIVE SUMMARY

In 1995, the Program Analysis and Evaluation branch of the Office of the Secretary of Defense (OSD PA&E) created the Defense Resource Management Model (DRMM). The DRMM provides Eastern European countries with small to medium size defense forces the capability to estimate their force's capability and cost. The DRMM contains detailed report writing that allows a nation's military posture to be described by: how its forces are organized and equipped; how it staffs its forces; how it scales its peacetime training rates; and how it practices budgeting and accounting. The DRMM's design allows users to create and modify fundamental characteristics (i.e., force structure, equipment, manning, activity level, war reserves inventory and time-frame) of a defensive force to investigate cost and effectiveness.

The DRMM does not currently provide the maximum effectiveness possible within budget limitations or the minimum cost necessary to obtain desired force effectiveness. Users must manually input force characteristics to provide comparisons, which is time intensive and often sub-optimal. To be a more effective decision aid, the DRMM needs expansion beyond the database level. The structure of the model presents an opportunity for optimization to increase its effectiveness as a decision support system.

This thesis develops an extension to the DRMM, the Defense Resource Management Optimization Model (DRMOM). The DRMOM is a multi-objective linear program. The linear program suggests yearly unit, activity, manning, equipment, and war

reserve levels. The DRMOM allows investigation of cost effectiveness tradeoffs and timely scenario comparison.

Possible uses of the linear program are demonstrated using a hypothetical, but realistic, Eastern European Force supplied by OSD PA&E. Results show the ability to maintain current capability but reduce annual spending by up to 30 percent. Other results show how capability can be increased nearly 50 percent over a five-year time horizon by increasing annual budget levels ten percent above their current levels. The problem may be solved on a desktop PC, with a 486 or Pentium processor, in less than two minutes.

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I would like to recognize Professor Mikhail Tsypkin for his involvement in this effort. As a National Security Affairs professor, he broke new ground by committing himself to this thesis, and provided valuable insight into the inner workings of the Eastern European planning process.

Most importantly, I want to dedicate this thesis to my wife Traci in recognition of her love and untiring support throughout my career, as an officer and student, which made all of this possible.

I. INTRODUCTION

A. THE DEFENSE RESOURCE MANAGEMENT MODEL

In 1995 the Program Analysis and Evaluation branch of the Office of the Secretary of Defense (OSD PA&E) created The Defense Resource Management Model (DRMM) [OSD PA&E, 1995]. The DRMM is a Windows based database system that provides Eastern European countries with small to medium size defense forces the capability to estimate their force's cost and capability. The DRMM contains detailed report writing that allows a nation's military posture to be described by: how its forces are organized and equipped; how it staffs its forces; how it scales its peacetime training rates; and how it practices budgeting and accounting. The DRMM's design allows users to create and modify force characteristics (i.e., force structure, equipage, manning, peacetime training, wartime stockpiles and time-frame), and thereby search for beneficial changes. This approach is, however, time intensive and potentially sub-optimal. This thesis expands the DRMM beyond its current database level with the addition of a linear programming model. The linear program provides changes to force characteristics that maximizes effectiveness within annual budget limitations or minimizes the cost necessary to obtain a desired force effectiveness.

B. ESTIMATING COST AND CAPABILITY

This thesis describes the DRMM using three primary areas: unit composition, capability assessment and force costing. The following paragraphs provide a summary of these areas. Detailed information can be found in the Defense Resource Management Model Guide [OSD PA&E, 1995]. Figure 1.1 shows an example of the DRMM opening screen.

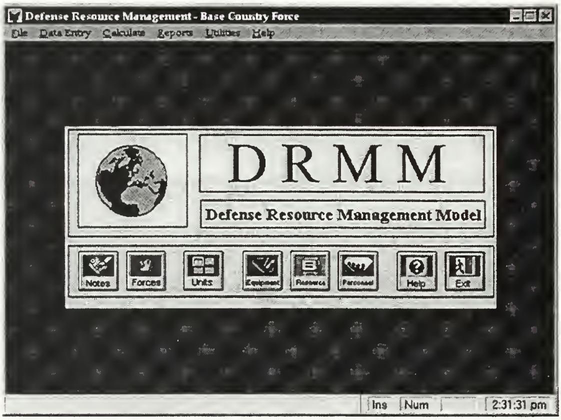

Figure 1.1. The Defense Resource Management Model opening screen. Accessible from this screen are unit, equipment, resource and personnel sub-areas that contain detailed capability and costing information.

1. Units within the Country's Defensive Force

The DRMM allows any user defined organization within its force to be represented as a unit (i.e., infantry division, artillery brigade). The DRMM requires the user to input the hierarchical relationships between units so it can provide summaries of the force structure at any specified level. For example, you may view an infantry division's structure independently, or as an aggregate of its subordinate brigade units. Individual brigade structure is available as well, by selecting the desired unit from those in the division subdirectory. Figure 1.2 shows an example of how the DRMM classifies the force structure data.

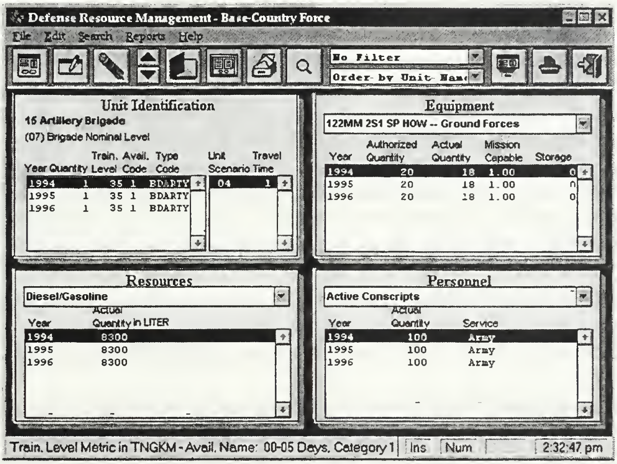

Figure 1.2. The DRMM screen representing the classification of unit, personnel, equipment and WRM quantities and codes.

2. Capability Assessment

The DRMM estimates authorized, actual, and effective force capabilities. A unit's authorized capability is the sum over all equipment types of the unit's authorized equipment quantity multiplied by the equipment's corresponding TASCFORM [Regan and Downey, 1993] score. Similarly, the DRMM computes actual capability based on actual equipment quantities. Lastly, the DRMM calculates effective force capability by multiplying actual capability by the unit's equipment mission capable rate (a user input between zero and one) and training level (also a user input between zero and one). These multiplicative factors allow the user to degrade actual capability for resource shortfalls in areas such as manning, logistics and war reserve materiel (WRM).

3. Force Costing

The same force structure data used to make capability assessments is used to estimate annual funding requirements. The DRMM estimates annual funding requirements by using user defined units, unit resource requirements (e.g., personnel, equipment, WRM), and cost estimates for personnel, peacetime unit operation, equipment procurement, increases to WRM stockpiles, and other miscellaneous costs such as investment or project costs. These cost estimates are supplied in cost accounts (e.g., pay, base support, equipment support) that match the fiscal and accounting practices of the country. The DRMM multiplies cost estimates within an account by the number of units, personnel, equipment, and level of WRM, as appropriate, to determine annual costs. Cost accounts may be classified as either fixed or variable. Variable cost accounts typically reflect fiscal requirements associated with changing levels of personnel and equipment, as well as unit and equipment activity levels. The DRMM generates reports on annual unit and equipment operating costs, personnel, equipment modernization, WRM, and other miscellaneous costs. We discuss these reports in detail below.

a. Units and Equipment

Unit size, equipment quantities and peacetime activity level (e.g., training kilometers, flying hours, etc.) form the basis of recurring annual unit operating costs. These costs include the costs of combat and combat support units, equipment operation, headquarters and command organizations, and any other activities such as communications, training, and logistic centers. These costs may also include the cost of operating and maintaining defense facilities.

The DRMM considers unit operating costs and equipment operating costs separately to help realize the affordability of modernization alternatives. Units incur equipment operating costs by the operation and support of major equipment items. Equipment operating costs account for fuel; spare parts; supplies; and ammunition consumed.

b. Personnel

The DRMM personnel costs (considered variable) include the direct costs of pay and indirect costs such as those for incurred medical support, housing or travel. The DRMM estimates total personnel costs by combining unit manning and individual personnel costs that are identified by personnel type and service. The DRMM contains four broad personnel categories: active duty military; reserve military; civilians, and retirees/pensioners. Specific personnel types, such as officers, enlisted or conscript personnel, exist within each of these categories.

c. Equipment Modernization

Fixed equipment modernization costs reflect net increases in equipment quantities. The DRMM adds the cost of new equipment based on procurement cost factors. The DRMM allows procurement costs to occur over a multi-year period, relative to the year of actual equipment delivery.

d. War Reserve Materiel Stockpiles

Fixed WRM costs reflect projected changes in resource levels by specific materiel item (e.g., JP-4, diesel fuel, POL, etc.). Expenses occur in the year in which stockpile inventories increase.

e. Miscellaneous

In all defense programs there are funding requirements that you cannot estimate directly from the force composition. The DRMM records and forecasts these miscellaneous expenses as project costs. Typical project costs record investments such as the construction of new facilities, funding for a general category of research programs, specific research projects or the procurement of equipment that is not included in the equipment modernization calculation (e.g., trucks, electronics and support equipment that do not have TASCFORM scores). Even though labeled “project costs,” this DRMM feature records costs for general budget expenses that do not fit in another part of the model.

Investment projects generally apply for any one-time requirement or programs that reflect independent policy decisions. Projects are essential to model the overall costs of a defense program. For example, many countries fund a continuing level of research in support of defense activities. The DRMM establishes a project, "Defense Research," and assigns funding levels that vary year by year. In addition, an investment project could be created for the research and development of a specific weapon system.

C. MAKING THE DRMM A MORE EFFECTIVE DECISION SUPPORT SYSTEM

This thesis develops an extension to the DRMM, the Defense Resource Management Optimization Model (DRMOM). The DRMOM is a multi-objective linear program that maintains the data structure of the original DRMM. The extension employs linear programming to suggest optimal yearly unit levels, activity, manning, equipment, and WRM levels. The DRMOM extension allows investigation of cost effectiveness tradeoffs and timely scenario comparison.

Chapter II discusses previous research related to this thesis. We begin by discussing the theory behind soviet manpower planning, followed by a discussion of previous mathematical approaches to manpower modeling. Lastly, we discuss the background of TASCFORM equipment scoring and its impact on model validity. Chapter III presents the linear program developed in this thesis. Chapter IV presents both a demonstration data set and a generic Eastern European force data set. We then demonstrate the DRMOM using both data sets and discuss the results. Chapter V makes recommendations based on the results of this thesis and suggests areas for further research.

II. RELATED RESEARCH

This chapter discusses previous research related to this thesis. We begin by discussing past and present methodology behind Soviet planning. A discussion of manpower planning models, and recent examples of their use, is next. Finally, we present the methodology on TASCFORM scoring and its impact as a measure of effectiveness (MOE) in this thesis.

A. SOVIET PLANNING

Zauberman (1976) emphasizes the concept of price, or budget, as a parameter in decision making is quite new in Soviet thinking. Until the mid-1950's, traditional Soviet planning doctrine treated price as a recording, or accountancy, tool. There was little relationship between the methodology of planning and the economic mechanism itself. Planning was fundamentally thought of as an operation in quantity physical terms: price would reflect such relations. Grossman (1960) points out that this price corresponded to the very limited technical possibilities of the era, as well as the methodology of direct-centralist normative (mandatory), or non-parametric, planning.

Zauberman further states that new Soviet pricing theory has brought about profound change. The concept of price, and the relationship between plan optimality and pricing, has become part of their planning theory. The idea of profit maximization as an optimality criterion provided Soviet planners with instruments of broad strategic optimization, which expected to help improve the quality of their planning methods.

We believe that Eastern European military planners, even with the breakup of the Warsaw Pact, are fully dependent on Soviet concepts of an optimality and price relationship [Tsypkin, 1996]. This can supply fertile ground for the introduction of the DRMOM. By creating the DRMM, PA&E supplies the Eastern European countries with a force capability and cost accounting aid. The DRMOM advances the DRMM to the next phase in its development, optimization.

B. MANPOWER PLANNING MODELS

This thesis presents an optimization solution to force modernization planning and expenditure. Coyle (1992) discusses some of the problems with planning defense expenditure and suggests that there is a need for aggregated quantitative optimization models to support the task. He presents a model that determines optimum patterns of expenditure for a hypothetical case.

Whereas our "total force" approach breaks new ground in this area of study, there are numerous examples in the related field of manpower planning models.

Manpower planning, which is a technical term from the literature of personnel administration [Dunnette, 1966], refers to the activities associated with personnel recruitment, assignment, training, promotion and transfer. It also includes the forecasts and assessments of the demands and supplies for skills and jobs. In simpler terms, manpower planning determines the number of personnel and their skills that best meet the future operational requirements of an enterprise [Gass, 1991].

Grinold and Marshall (1977) categorize manpower models as being either cross-sectional or longitudinal. Cross-sectional, or Markov, models deal with the cross-sectional structure of a system at a given time. They describe how a manpower system changes from one set of levels to another without the need for information about historical personnel movement. Gass (1991) relates these models to their use in forecasting personnel inventory levels based on known transition rates (e.g., given a work force described by time, skills, function and job title at the beginning of a planning period, determine the composition of the force at the end of the planning period). In an earlier work, Gass (1988) applies this theory to project the flow of an initial U.S. Army enlisted force to a future force over a 20-year horizon. This type of model requires little data. The disadvantage of the cross-sectional model is its structural fault when used to describe manpower flow; it is time independent. Raghavendra (1991) proposes a Bivariate Markov model that addresses this problem by considering time and performance in a Bivariate distributional framework.

Longitudinal manpower models are much more general than the cross-sectional models, and describe the flow of a group, or cohort, through the manpower system over time. This model incorporates more realistic personnel flows, but requires extensive data that is not always available [Marshall, 1977].

Grinold and Marshall (1977) further describe manpower optimization models based on these cross-sectional and longitudinal models. The optimization models here are stressed as being only part of the planning process, and are not intended to dominate that process. Vajda (1985) applies a linear programming approach to a discrete renewal manpower model for the development of a graded population. He considers which structures can be attained from a given structure after one or two time steps, and which structures can be re-attained after one or two steps.

Military applications of manpower modeling include optimization models for U.S. Army Planning and Programming. Miller (1984) describes the Army Personnel Planning System, which assists the U.S. Army in addressing personnel planning issues having mid and long range implications. Durso and Donahue (1995) develop a life cycle model to study the impact on the U.S. Army's enlisted force. They determine a downsizing strategy that guarantees optimal manning of the active army and analyze active and reserve component force-mix alternatives. Rogers (1991) develops a multi-objective linear program to determine optimal levels of U.S. Navy enlisted personnel. Klingman, Mead, and Phillips (1984) apply two prototype network optimization models to military manpower planning: an enlisted personnel assignment model and a military officer strength forecast model.

C. MEASURE OF EFFECTIVENESS

The RAND corporation defines an objective as the first required element of military decision support [RAND, 1983]. Weapon system valuation quantifies this objective as a MOE. According to Taylor (1980), numerical values to indicate military effectiveness have been in use for at least 35 years. Such values are still in use today, both by force planners and in combat models. Dupuy (1985) develops a detailed methodology for computing effectiveness (lethality) values for weapon systems through the use of system performance characteristics. He uses these values to predict or explain battle outcomes, and validates his methodology with historical data.

The TASCFORM methodology, used in the DRMM and the DRMOM, computes a numerical score for a weapon system by weighing its performance characteristics. TASCFORM bases its calculation on a comparison of performance ratios with a "baseline system," accounting for factors such as payload, weapon range, and system mobility [Regan and Downey, 1993].

III. THE DEFENSE RESOURCE MANAGEMENT OPTIMIZATION MODEL

The DRMOM creates an optimal force modernization plan, at a yearly level of detail, for a finite user defined planning horizon. The DRMOM suggests this plan by employing either capability or budget objectives. We achieve the former by maximizing the force's capability within a given yearly budget. The latter minimizes cost while maintaining desired capability.

The DRMOM decision variables determine yearly unit activity, manpower, equipment, and WRM stockpile levels. Additional decision variables track yearly additions and subtractions to these values, as well as the number below authorized levels of manning, equipment, and war reserve materiel in each unit.

The DRMOM uses a series of constraints that place limitations on the requisite activity, manning, equipment and war reserve levels within each unit. These limitations are expressed as linear functions of the decision variables. Unit levels are subject to limits on the minimum and maximum yearly number of each unit type, as well as unit mix requirements that maintain user defined ratios between units. Unit activity levels are subject to minimum and authorized limits, as well. Personnel levels must remain between actual and authorized levels.

A similar set of constraints control equipment and WRM quantities, with additional constraints for transfer of like equipment and resources among units. In some cases each equipment item requires a minimum quantity of war reserve materiel (i.e., crew, fuel, ammunition, repair kits). The DRMOM considers these minimums when determining the WRM levels in units that have increases or decreases in equipment quantities.

The DRMOM approximates the force capability calculation used in the DRMM. The DRMM calculates force capabilities as the product of a unit's equipment mission capable rate (a user input between zero and one), training level (also, a user input between zero and one), and TASCFORM equipment capability scores. Incorporating this product into the DRMOM would not be appropriate, since the equipment mission capable rates and the training level can change due to changes in the DRMOM decision variables. Instead, the DRMOM approximates the DRMM calculation using the TASCFORM equipment capability score for a unit's authorized level of equipment and penalizing for shortfalls in manning, activity level, equipment, and WRM. By penalizing for these shortfalls, the DRMOM approximates the user supplied training level and mission capable rates.

We assume yearly project costs occur regardless of force structure modification. Because project costs cover such a broad range of applications, the costs are not considered in the optimization; but we add the costs to the total budget. The decision to include or exclude project costs in the modernization package is left to the judgment of the decision maker.

The remainder of this chapter presents the mathematical formulation of the DRMOM, followed by a description of each constraint.

A. INDEX SETS

u	Unit types (e.g., Airwing, Mechanized Division);
y	Years (e.g., 1995, 1996, ..., 2000);
p	Personnel types (e.g., Officer, Enlisted, Conscript);
s	Service (e.g., Army, Air Force);
e	Equipment items (e.g., Tanks, Aircraft);
r	Resource Items (e.g., Crews, Ammo, Fuel); and
a	Cost Accounts (e.g., R&D, Construction).

B. COST INPUT DATA

Unit Operating Costs:

$FixedUnit_{u,a}$	Annual fixed cost in account a per unit type u;
$BuyUnit_{u,a}$	Cost in account a to add a unit u;
$SellUnit_{u,a}$	Cost in account a to subtract a unit u; and
$VblAct_{u,a}$	Annual variable cost for activity level in account a per unit type u.

Personnel Costs:

$VblPers_{u,p,s,a}$	Annual variable cost in account a per personnel type p from service s and unit type u;
$BuyPers_{u,p,s,a}$	Cost in account a to add personnel type p from service s and unit type u; and
$SellPers_{u,p,s,a}$	Cost in account a to subtract personnel type p from service s and unit type u.

Equipment Operating Costs:

$FixedEqp_{e,a}$	Annual fixed cost in account a per equipment item e; and
$VblEqp_{e,a}$	Annual variable cost for activity level in account a per equipment item e.

Equipment Modernization Costs:

$BuyEqp_{e,a}$	Procurement cost for equipment item e in account a; and
$SellEqp_{e,a}$	Disposal cost for equipment item e in account a.

Project Costs:

$Project_{y,a}$	Total project costs in account a in year y.

War Reserve Materiel Costs:

$BuyRes_{r,a}$	Procurement cost for resource item r in account a.

Budget Available:

$Budget_{y\,a}$	Constant dollars in account a available in year y.

Unit Mix:

$MinUnit_{u,y}$	Minimum number of unit u in year y;
$MaxUnit_{u,y}$	Maximum number of unit u in year y; and
$MixUnit_{u,u'}$	Minimum number of unit u required for each unit u'.

C. CAPABILITY INPUT DATA

Below, we make the assumption that personnel and equipment quantities must remain between those currently available, and those authorized for each unit.

Personnel Quantities:

$PersBelow_{u,y,p,s}$ The fraction of personnel type p per unit u, service s and year y allowed below authorized.

$$PersBelow_{u,y,p,s} = 1 - \text{MIN}\left\{\frac{ActPers_{u,y,p,s}}{PersAuth_{u,y,p,s}}, 1\right\}, \text{ where}$$

$PersAuth_{u,y,p,s}$ Authorized number of personnel type p from service s per unit u during year y; and

$ActPers_{u,y,p,s}$ Actual number of personnel type p from service s per unit u during year y.

Equipment Quantities:

$EqpBelow_{u,y,e}$ The fraction of equipment e per unit u and year y allowed below authorized.

$$EqpBelow_{u,y,e} = 1 - \text{MIN}\left\{\frac{ActEqp_{u,y,e}}{EqpAuth_{u,y,e}}, 1\right\}, \text{ where}$$

$EqpAuth_{u,y,e}$ Authorized quantity of equipment e per unit u in year y; and

$ActEqp_{u,y,e}$ Actual quantity of equipment e per unit u in year y.

Capability:

$Benefit_{u,y,e}$ Capability of equipment e in unit u in year y.

$$Benefit_{u,y,e} = \left(CapScore_e \cdot EqpAuth_{u,y,e}\right),$$ where

$CapScore_e$ TASCFORM score for equipment item e.

Capability Requirement:

$CapMin_y$ The minimum total capability required in year y.

Resources:

$EqpRes_{e,r}$ Minimum resources r required per equipment item e;

$ResMin_{u,y,r}$ Minimum quantity of resource item r per unit u in year y; and

$ResAuth_{u,y,r}$ Authorized quantity of resource item r per unit u in year y.

Activity Level:

$ActMin_{u,y}$ Minimum fraction per unit type u activity level in year y; and

$ActAuth_{u,y}$ Authorized activity level per unit type u in year y.

Objective Function Penalties:

$PerPen_{p,s}$ Penalty per personnel type p from service s below authorized;

$ResPen_{u,y,r}$ Penalty per resource item r per unit type u in year y below authorized;

$ActPen_{u,y}$ Penalty for reducing activity level of unit type u below authorized in year y;

$PslkPen_{p,s}$ Penalty per personnel type p from service s below actual;

$EslkPen_e$ Penalty per equipment type e below actual;

$RslkPen_r$ Penalty per resource item r below actual; and

$MinslkPen_r$ Penalty per resource item r below that required by equipment type e.

D. VARIABLES

Objectives (continuous variables unrestricted in sign):

B Budget objective function value; and

Z Capability objective function value.

Units (nonnegative continuous variables):

$Unit_{u,y}$ Number of unit type u in year y;

$UnitAdd_{u,y}$ Unit type u added at end of year y; and

$UnitSub_{u,y}$ Unit type u subtracted at end of year y.

Equipment (nonnegative continuous variables):

$Eqp_{u,y,e}$	Number of equipment type e per unit u in year y;
$EqpAdd_{u,y,e}$	Equipment type e added to units of type u at end of year y; and
$EqpSub_{u,y,e}$	Equipment type e subtracted from units of type u at end of year y.

Personnel (nonnegative continuous variables):

$Pers_{u,y,p,s}$	Number of personnel type p from service s per unit type u in year y;
$PersAdd_{u,y,p,s}$	Personnel type p from service s added to unit type u at end of year y; and
$PersSub_{u,y,p,s}$	Personnel type p from service s subtracted from unit type u at end of year y.

War Reserves Materiel (nonnegative continuous variables):

$Res_{u,y,r}$	Number of resource item r for unit type u in year y;
$ResAdd_{u,y,r}$	Resource item r added to unit type u at end of year y; and
$ResSub_{u,y,r}$	Resource item r subtracted from unit type u at end of year y.

Reduction Between Authorized and Minimum (nonnegative continuous variables):

$EqpRed_{u,y,e}$	Reduction of equipment e in unit type u in year y;
$PerRed_{u,y,p,s}$	Reduction of personnel p in service s in unit type u in year y; and
$ResRed_{u,y,r}$	Reduction of resource r in unit type u in year y.

Reduction Below Minimum (nonnegative continuous variables):

$PerSlk_{u,y,p,s}$ Number of personnel type p from service s per unit type u below minimum in year y;

$EqpSlk_{u,y,e}$ Equipment e below minimum in unit type u in year y;

$ResSlk_{u,y,r}$ Resource r below minimum in unit type u in year y; and

$MinSlk_{u,y,r}$ Resource r below minimum equipment requirements in unit type u in year y.

Activity Level:

$Act_{u,y}$ Total activity level for unit type u in year y; and

$ActRed_{u,y}$ Total activity level reduction for unit type u in year y.

Equipment and War Reserves Transfer:

$EqpTrns_{u,y,e}$ Equipment e transferred from unit type u at end of year y; and

$ResTrns_{u,y,r}$ Resource r transferred from unit type u at end of year y.

E. OBJECTIVE FUNCTIONS

As mentioned earlier, the DRMOM offers two different objective functions.

1. Minimize Cost

$$\text{MIN B} = \sum_{y,a}\left[\begin{array}{l} \sum_{u}\begin{pmatrix} FixedUnit_{u,a}\cdot Unit_{u,y} + VblAct_{u,a}\cdot Act_{u,y} \\ + BuyUnit_{u,a}\cdot UnitAdd_{u,y} + SellUnit_{u,a}\cdot UnitSub_{u,y} \end{pmatrix} \\ + \sum_{u,p,s}\begin{pmatrix} VblPers_{u,p,s,a}\cdot Pers_{u,y,p,s} + BuyPers_{u,p,s,a}\cdot PersAdd_{u,y,p,s} \\ + SellPers_{u,p,s,a}\cdot PersSub_{u,y,p,s} \end{pmatrix} \\ + \sum_{u,e}\begin{pmatrix} \left(FixedEqp_{e,a} + VblEqp_{e,a}\right)\cdot Eqp_{u,y,e} \\ + BuyEqp_{e,a}\cdot EqpAdd_{u,y,e} + SellEqp_{e,a}\cdot EqpSub_{u,y,e} \end{pmatrix} \\ + \sum_{u,r} BuyRes_{r,a}\cdot ResAdd_{u,y,r} \end{array}\right] \tag{1}$$

2. Maximize Capability

$$\text{MAX Z} = \sum_{u,y}\left[\begin{array}{l} \sum_{e}\begin{pmatrix} Benefit_{u,y,e}\cdot Unit_{u,y} - Capscore_{e}\cdot EqpRed_{u,y,e} \\ - EslkPen_{e}\cdot EqpSlk_{u,y,e} \end{pmatrix} \\ - \sum_{p,s}\left(PerPen_{u,p,s}\cdot PerRed_{u,y,p,s} + PslkPen_{p,s}\cdot PerSlk_{u,y,p,s}\right) \\ - \sum_{r}\begin{pmatrix} ResPen_{u,y,r}\cdot ResRed_{u,y,r} + ActPen_{u,y}\cdot ActRed_{u,y} \\ RslkPen_{r}\cdot ResSlk_{u,y,r} + MinslkPen_{r}\cdot MinSlk_{u,y,r} \end{pmatrix} \end{array}\right] \tag{2}$$

F. CONSTRAINTS

The following are the DRMOM constraints. For modeling purposes, we call the initial year (y=0) of the planning horizon the base year. We fix base year manning, activity, equipment, and WRM at actual levels.

Units:

$$Unit_{u,y} = Unit_{u,y-1} + UnitAdd_{u,y-1} - UnitSub_{u,y-1} \qquad \forall\, u,y \qquad (3)$$

$$Unit_{u,y} \geq MinUnit_{u,y} \qquad \forall\, u,y \qquad (4)$$

$$Unit_{u,y} \leq MaxUnit_{u,y} \qquad \forall\, u,y \qquad (5)$$

$$Unit_{u,y} \geq MixUnit_{u,u'} \cdot Unit_{u',y} \qquad \forall\, u,u',y \qquad (6)$$

Activity Level:

$$Act_{u,y} \geq ActAuth_{u,y} \cdot Unit_{u,y} - ActRed_{u,y} \qquad \forall\, u,y \qquad (7)$$

$$ActRed_{u,y} \leq \left(ActAuth_{u,y} \text{ - } ActMin_{u,y}\right) \cdot Unit_{u,y} \qquad \forall\, u,y \qquad (8)$$

Personnel:

$$Pers_{u,y,p,s} = Pers_{u,y-1,p,s} + PersAdd_{u,y-1,p,s} - PersSub_{u,y-1,p,s} \qquad \forall\, u,y,p,s \qquad (9)$$

$$Pers_{u,y,p,s} = PersAuth_{u,y,p,s} \cdot Unit_{u,y} - PerRed_{u,y,p,s} - PerSlk_{u,y,p,s} \qquad \forall\, u,y,p,s \qquad (10)$$

$$PerRed_{u,y,p,s} \leq \left(PersAuth_{u,y,p,s} \cdot Unit_{u,y}\right) \cdot \left(PersBelow_{u,y,p,s}\right) \qquad \forall\, u,y,p,s \qquad (11)$$

Equipment:

$$Eqp_{u,y,e} = Eqp_{u,y-1,e} + EqpAdd_{u,y-1,e} + EqpTrns_{u,y-1,e} - EqpSub_{u,y-1,e} \qquad \forall\, u,y,e \quad (12)$$

$$Eqp_{u,y,e} = EqpAuth_{u,y,e} \cdot Unit_{u,y} - EqpRed_{u,y,e} - EqpSlk_{u,y,e} \qquad \forall\, u,y,e \quad (13)$$

$$EqpRed_{u,y,e} \le EqpAuth_{u,y,e} \cdot Unit_{u,y} \cdot EqpBelow_{u,y,e} \qquad \forall\, u,y,e \quad (14)$$

$$\sum_u EqpTrns_{u,y,e} \le \sum_u EqpSub_{u,y,e} \qquad \forall\, y,e \quad (15)$$

War Reserves:

$$Res_{u,y,r} = Res_{u,y-1,r} + ResAdd_{u,y-1,r} + ResTrns_{u,y-1,r} - ResSub_{u,y-1,r} \qquad \forall\, u,y,r \quad (16)$$

$$Res_{u,y,r} = ResAuth_{u,y,r} \cdot Unit_{u,y} - ResRed_{u,y,r} - ResSlk_{u,y,r} \qquad \forall\, u,y,r \quad (17)$$

$$ResRed_{u,y,r} \le \left(ResAuth_{u,y,r} - ResMin_{u,y,r}\right) \cdot Unit_{u,y} \qquad \forall\, u,y,r \quad (18)$$

$$\sum_u ResTrns_{u,y,r} \le \sum_u ResSub_{u,y,r} \qquad \forall\, y,r \quad (19)$$

$$Res_{u,y,r} \ge \left(\sum_e Eqp_{u,y,e} \cdot EqpRes_{e,r}\right) - MinSlk_{u,y,r} \qquad \forall\, u,y,r \quad (20)$$

Capability:

$$\sum_u \left[\begin{array}{l} \sum_e \begin{pmatrix} Benefit_{u,y,e} \cdot Unit_{u,y} - Capscore_e \cdot EqpRed_{u,y,e} \\ - EslkPen_e \cdot EqpSlk_{u,y,e} \end{pmatrix} \\ - \sum_{p,s} \left(PerPen_{u,p,s} \cdot PerRed_{u,y,p,s} + PslkPen_{p,s} \cdot PerSlk_{u,y,p,s} \right) \\ - \sum_r \begin{pmatrix} ResPen_{u,y,r} \cdot ResRed_{u,y,r} + ActPen_{u,y} \cdot ActRed_{u,y} \\ RslkPen_r \cdot ResSlk_{u,y,r} + MinslkPen_r \cdot MinSlk_{u,y,r} \end{pmatrix} \end{array} \right] \qquad \forall\, y \quad (21)$$

$$\ge CapMin_y$$

Budget:

$$
\begin{aligned}
&\sum_{u}\begin{pmatrix} FixedUnit_{u,a}\cdot Unit_{u,y} + VblAct_{u,a}\cdot Act_{u,y} \\ + BuyUnit_{u,a}\cdot UnitAdd_{u,y} + SellUnit_{u,a}\cdot UnitSub_{u,y} \end{pmatrix} \\
&+\sum_{u,p,s}\begin{pmatrix} VblPers_{u,p,s,a}\cdot Pers_{u,y,p,s} + BuyPers_{u,p,s,a}\cdot PersAdd_{u,y,p,s} \\ + SellPers_{u,p,s,a}\cdot PersSub_{u,y,p,s} \end{pmatrix} \\
&+\sum_{u,e}\begin{pmatrix} \left(FixedEqp_{e,a} + VblEqp_{e,a}\cdot Eqp_{u,y,e}\right) \\ + BuyEqp_{e,a}\cdot EqpAdd_{u,y,e} + SellEqp_{e,a}\cdot EqpSub_{u,y,e} \end{pmatrix} \\
&+\sum_{u,r} BuyRes_{r,a}\cdot ResAdd_{u,y,r} \\
&\le Budget_{y,a} - Project_{y,a} \qquad\qquad \forall\, y,a
\end{aligned}
\tag{22}
$$

Equations (1) and (2), the objective functions, either minimize cost or maximize capability. We minimize cost by summing all fixed, variable, procurement, and disposal costs (e.g., the cost of decommissioning a unit, personnel, or piece of equipment) over a given time horizon. Fixed and variable equipment costs ($FixedEqp_{e,a}$ and $VblEqp_{e,a}$) are summed then multiplied by the number of equipment items. Traditionally, fixed costs (e.g., the DRMOM unit and equipment fixed costs) are treated as binary (i.e., accept either all or none of the cost) [Baumol, 1977]. Because the DRMOM uses continuous variables to control unit and equipment quantities, we allow fractional fixed costs. This is inconsistent with traditional thought, but allows the DRMOM to remain linear.

Using equation (2), capability is maximized over a given time horizon, penalized for shortfalls in personnel, equipment, and war reserves below authorized levels.

Capability is further penalized if these shortfalls fall below actual (minimum) levels, which we model using elastic variables.

Equation (3) tracks the yearly addition and subtraction of each unit type. Equations (4) and (5) ensure the number of units for a given year satisfy minimum and maximum requirements. Equation (6) requires the number of units for a given year to be greater than or equal to the product of a related unit's quantity mix and the number of related units.

Equation (7) ensures that the yearly activity level of a given unit is greater than or equal to the authorized activity level, minus a reduction. This reduction is constrained in equation (8), to be less than or equal to the difference between the authorized and actual (minimum) specified activity level.

Equation (9) tracks the yearly addition and subtraction of each personnel type in each unit. Equation (10) states the number of personnel in a unit for a given year must be equal to the authorized number of personnel minus a reduction. There are two levels of reduction allowed. Equation (11) constrains the first per unit reduction level ($PerRed_{u,y,p,s}$) to be less than or equal to the difference between authorized and actual (minimum) levels. The other reduction allowed ($PerSlk_{u,y,p,s}$) is not limited, but per unit violation is larger than $PerRed_{u,y,p,s}$. It is important to note that constraints (9) to (11) control the number of unit support personnel. Those personnel required as crews to operate equipment are controlled within the WRM constraints to be consistent with the DRMM.

In a similar manner, equations (12) to (14) determine the appropriate number of equipment items. Equation (15) ensures legitimate transfer of equipment between units.

Equations (16) to (18) determine the appropriate level of war reserves, as in the equations for manning and equipment. Equation (19) ensures transferred reserves are less than or equal to all unit war reserve reductions in a given year. Equation (20) provides each equipment item with the required quantity of resources.

Equation (21) requires annual capability to be greater than or equal to a given level. This constraint can be used when minimizing objective (1).

Lastly, equation (22) requires that all annual personnel, equipment, WRM and unit operating costs be less than a given budget. This constraint can be used when maximizing objective (2).

IV. COMPUTATIONAL EXPERIENCE

All data in this thesis is unclassified. We use Microsoft Excel (Microsoft Corporation, 1995) to convert the DRMM database to text format suitable for input to the DRMOM. The DRMOM is generated using the General Algebraic Modeling System [Brooke, Kendrick and Meeraus, 1992]. All computation results are collected using the CPLEX solver [CPLEX Optimization, INC., 1994].

A. FORCE MODERNIZATION PLANS

We examine two force modernization data sets. OSD PA&E demonstrates the DRMM with a small hypothetical data set. We use this data set to illustrate the advantages of the new DRMOM model, and refer to it as the "Demonstration Data." The second data set contains actual force and costing data for an Eastern European force, henceforth referred to as the "Eastern European Force Data." For the remainder of this chapter, all currencies are in terms of monetary units (MU).

1. The Demonstration Data

Our examination of this hypothetical force covers a one to three year time horizon. To introduce the data, a summary of the fundamental unit structure is in Table 4.1. Table 4.2 shows personnel types and associated military service. Table 4.3 shows the Demonstration Data equipment types and TASCFORM scores, followed by the Force's resource types in Table 4.4. Cost accounts for this data are in Table 4.5.

Unit Code	Quantity	Description
MOD	1	Ministry of Defense
GS	1	General Staff
HQAF	1	Headquarters, Air Force
HQARMY	1	Headquarters, Army
HQNAVY	1	Headquarters, Navy
DVMECH	2	Mechanized Division
BDMECH	5	Mechanized Brigade
BDARTY	1	Artillery Brigade
BDARMR	1	Armored Brigade
BDCS	1	Combat Support Brigade
CORPS1	1	1^{st} Army Corps
FLSUB1	1	1^{st} Submarine Flotilla
AWING	1	1^{st} Air Wing

Table 4.1. Unit codes, their quantity and description for units in the Demonstration Data. For this data set, units with the same unit code have identical costing and capability. For example, there is no difference between the first and the fifth BDMECH unit.

Personnel Code	Service	Description
ACONRG	A	Army Active Conscript
ACONRG	F	Air Force Active Conscript
ACONRG	M	Ministry of Defense Active Conscript
AENLRG	A	Army Active Enlisted
AENLRG	F	Air Force Active Enlisted
AENLRG	M	Ministry of Defense Active Enlisted
AOFFRG	A	Army Active Officer
AOFFRG	F	Air Force Active Officer
AOFFRG	M	Ministry of Defense Active Officer
CCIVRG	M	Ministry of Defense Civilian

Table 4.2. Personnel types, respective service, and descriptions for the Demonstration Data. Personnel types are categorized by service type to reflect the different average annual salaries between services. This accounts for differences in pay, for example, between an infantry officer and one who receives flight pay.

Equipment Code	Description	TASCFORM Score
ADZOP	MIG-29 Aircraft	18.346
CAGKI	Kilo Submarine	21.100
NADBA	Armored Personnel Carrier	0
PMICJ	T-55 Tank	1.596
PMLEA	T-72 Tank	3.783
PMLEL	T-80 Tank	4.531
UMMAL	122MM 2S1 Howitzer	3.248

Table 4.3. Equipment codes, descriptions, and TASCFORM scores for the Demonstration Data Set. These codes represent the type of equipment held by the units. The TASCFORM scores provide capability assessments of equipment that are independent of mission capable rates and operator crew training levels.

Resource Code	Description
POL1	Petroleum/Oil/Lubricants, Diesel
POL2	Petroleum/Oil/Lubricants, Aviation Fuel
POL3	Petroleum/Oil/Lubricants, Marine Diesel

Table 4.4. Resource codes and descriptions for the Demonstration Data Set. These codes represent the type of resource stockpiles held by individual units. One unit of POL2 resource, for example, represents 1000 liters of aviation fuel.

Cost Account Code	Description
RD_BAS	Research and Development, Basic Research
PRODAV	Procurement, Armored Vehicles
RD_DEV	Research and Development, Testing
CON_ADM	Construction, Command and Administration
PAY	Salaries
GENOPS	General Operations
BASESPT	Base Support
COMBTNG	Combat Training
FUEL	Equipment Fuel
OFFACT	Official Activities
INTAGR	International Agreements

Table 4.5. Cost account codes and descriptions for the Demonstration Data Set. These accounts categorize yearly personnel, operations, and investment costs. The cost accounts track both fixed and variable costs for all aspects of modernization.

2. The Eastern European Force Data

The Eastern European Force Data set contains all costing and force capability data for a mid-sized Eastern European force, over a time horizon of one to five years. There are 288 operational units categorized by seventeen superior/subordinate relationships. This force has sixteen personnel types and three service branches, employing over 900,000 troops. There are 45 different equipment types and 77 resource types. Unlike the demonstration data set, each unit has its own, specific characteristics regarding personnel, equipment, and WRM. Because of the requisite size of this data set, we present only partial data to demonstrate its characteristics.

Figure 4.1 illustrates the Eastern European Force command hierarchy. The force structure branches from its highest command level, the Ministry of Defense, into sixteen subordinate headquarters units. These units, in turn, command an assortment of subordinate units, and so on, to include all 288 units. We hold specific unit types constant, such as the Ministry of Defense and the subordinate headquarters, to preserve proper command structure. Additionally, subordinate units cannot exist unless their parent unit exists as well.

We examine the 36th Mechanized Regiment in detail as an example of the underlying structure of this data set. Figure 4.2 shows the 36th Mechanized Regiment's parent/subordinate unit hierarchy. Table 4.6 shows this unit's actual and authorized personnel, equipment and WRM levels.

Figure 4.1. The command structure of the Eastern European Force Data. Here we aggregate the 288 operational units into seventeen parent commands.

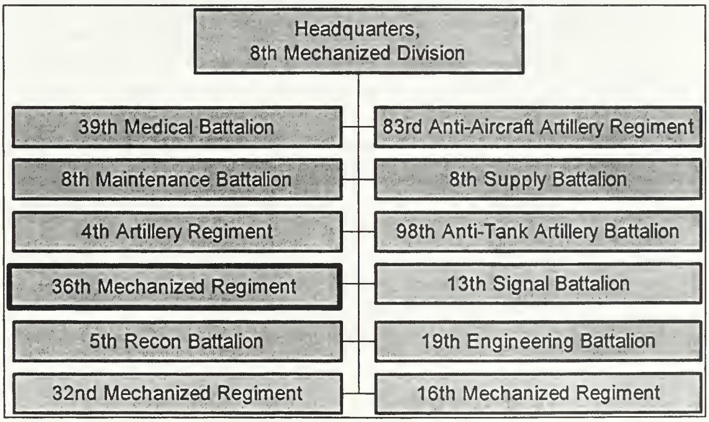

Figure 4.2. The command hierarchy of the 8th Mechanized Division. We detail the structure of the highlighted 36th Mechanized Regiment.

36TH MECHANIZED REGIMENT		
	YEARLY QUANTITY	
REQUIREMENT	ACTUAL	AUTH
Manpower:		
Army Active Conscripts	684	706
Army Active Officers	85	86
Civilians	72	104
Equipment:		
BMP-1	65	72
T-55 Tank	62	68
MTLB R-330P	5	6
BLG-67M	5	6
120 MM M120 MOD .38/43	12	13
122 MM 2S1 SP Howitzer	12	13
OT-64 Helicopter	18	20
War Reserve Materiel (WRM):		
120 MM M120 MOD .38/43 Ammo	12	13
120 MM M120 MOD .38/43 Repair Kits	12	13
122MM Artillery Ammo	12	13
122MM 2S1 SP Howitzer Repair Kits	12	13
BLG-67M Repair Kits	5	6
BMP-1 Ammo	65	72
BMP-1 Repair Kits	65	72
Diesel/Gasoline	179	198
MTLB R-330P Ammo	5	6
MTLB R-330P Repair Kits	5	6
Operator Crews	12	13
OT-64 Ammo	18	20
OT-64 Repair Kits	18	20
T-55 Ammo	62	68
T-55 Repair Kits	62	68

Table 4.6. The Eastern European force's 36th Mechanized Regiment's actual and authorized quantities of personnel, equipment, and WRM. This unit serves as an example of unit composition in the Eastern European force data set.

3. Cost Data

Due to the magnitude of both the Demonstration and Eastern European Force Data cost database, cost data is not shown. This user supplied input is contained within the DRMM. Table 4.7 lists these costs and their associated DRMOM parameter identification.

Data	DRMOM Parameter
Fixed unit costs	$FixedUnit_{u,a}$
Variable unit cost	$VblAct_{u,a}$
Variable personnel cost	$VblPers_{u,p,s,a}$
Fixed equipment cost	$FixedEqp_{e,a}$
Variable equipment cost	$VblEqp_{e,a}$
Equipment procurement cost	$Buyeqp_{e,a}$
Project cost	$Project_{y,a}$
WRM procurement cost	$BuyRes_{r,a}$

Table 4.7. User supplied cost input data and DRMOM parameters. This data is not explicitly shown for either the Demonstration data or the Eastern European Force Data, but is available from within the DRMM.

4. Data Needed by the DRMOM and Not Available in the DRMM

The enhanced capability of the DRMOM over the DRMM creates the need for data not currently available in the DRMM. We either approximate this data or set its value to zero. Table 4.8 lists this data and the approximation used. Table 4.9 lists the Demonstration Data approximated unit mix requirements.

Data	Approximation
Maximum units within a unit type ($MaxUnit_{u,y}$)	20
Minimum units within a unit type ($MinUnit_{u,y}$)	0
Minimum unit activity level ($ActMin_{u,y}$)	0.5
Maximum unit activity level ($ActAuth_{u,y}$)	1.0
Unit decommissioning costs ($SellUnit_{u,a}$)	0
Unit procurement costs ($BuyUnit_{u,a}$)	0
Equipment disposal costs ($SellEqp_{e,a}$)	0
Personnel hiring costs ($BuyPers_{u,p,s,a}$)	0
Personnel dismissal costs ($SellPers_{u,p,s,a}$)	0

Table 4.8. Required DRMOM data that is currently unavailable in the DRMM. This data is either approximated or set to zero for both data sets.

UNIT	HQAF	HQARMY	HQNAVY	DVMECH
BDMECH				3
BDARTY				3
CORPS1		1		
BDARMR		1		
BDCS		1		
AWING	1			
FLSUB1			1	

Table 4.9. Demonstration Data unit mix requirements. In this example case, there must be at least three BDMECH units for every DVMECH unit, and so on.

The DRMOM objective function penalties (i.e., $PerPen_{p,s}$, $PslkPen_{p,s}$, etc.) are user supplied inputs. To avoid a negative objective function, reasonable values must be assigned to these penalties. For both the Demonstration and Eastern European Force Data sets, $PerPen_{p,s}$, $ResPen_{u,y,r}$, and $ActPen_{u,y}$ are assigned a value of two. $PslkPen_{p,s}$, $EslkPen_e$, $RslkPen_r$, and $MinslkPen_r$ are assigned a value of ten.

The DRMOM includes data estimated from other DRMOM data that could be a user input. Presently, the available budget ($Budget_{y,a}$) and capability requirement ($CapMin_y$) are computed within the DRMOM. Allowable personnel and equipment quantity reductions ($PersBelow_{u,y,p,s}$ and $EqpBelow_{u,y,e}$) are estimated using actual and authorized quantities from the DRMM data.

B. COMPUTATIONAL EXPERIENCE

Implementation of both Demonstration Data and the Eastern European Force Data sets includes three example cases. Case One fixes the number of operational units at their actual values and determines the next year's budget and force capability at fully authorized quantities of personnel, activity, equipment and WRM. This involves either adding or subtracting current levels. This case gives us reference budget and capability. Case Two, allowing force structure modification, minimizes next year spending while maintaining reference capability. Case Three, again allowing force structure modification, maximizes capability over a given time horizon while holding the budget at or above the budget level determined in Case Two. By varying the budget above the Case Two level the tradeoff between budget and capability is demonstrated.

Solve time, for all cases using the Demonstration Data and Cases One and Two using the Eastern European Force Data, is under two minutes on a desktop PC. The Eastern European Force Data Case Three computation is approximately thirty minutes on an IBM RS6000 Model 590 Workstation.

1. The Demonstration Data

a. Case One: Actual Force at Authorized Levels

The planning horizon for Case One is one year. We fix all personnel, activity, equipment, and WRM levels at authorized levels. The model generates 510 variables, 327 constraints, and 767 non-zero's. Table 4.10 provides a summary of the DRMOM Case One results. Table 4.11 shows Case One budget allocation by cost account. Table 4.12 lists reference budget and capability levels.

UNIT	REQUIREMENT	YEAR		CAPABILITY	
		1994	1995	1994	1995
MOD	**Quantity:**	1	1		
	Personnel:				
	ACONRG	80	100		
	AENLRG	80	100		
	AOFFRG	220	200		
	CCIVRG	150	150		
GS	**Quantity:**	1	1		
	Personnel:				
	ACONRG	0	300		
	AENLRG	150	90		
	AOFFRG	250	300		
HQAF	**Quantity:**	1	1		
	Personnel:				
	ACONRG	25	50		
	AOFFRG	119	125		
HQARMY	**Quantity:**	1	1		
	Personnel:				
	ACONRG	25	50		
	AOFFRG	119	125		
HQNAVY	**Quantity:**	1	1		
	Personnel:				
	ACONRG	25	50		
	AOFFRG	119	125		
DVMECH	**Quantity:**	2	2		
	Personnel:				
	ACONRG	140	180		
	AENLRG	70	80		
	AOFFRG	110	100		
CORPS1	**Quantity:**	1	1		
	Personnel:				
	ACONRG	100	100		
	AENLRG	30	30		
	AOFFRG	30	30		

Table 4.10.A. Case One results. All personnel, equipment, and WRM quantities are fixed at authorized levels. For example, in 1994 the General Staff (GS) is understaffed with active duty conscripts and officers, but overstaffed with active duty enlisted personnel. The DRMOM modifies those personnel levels to their authorized values in 1995.

UNIT	REQUIREMENT	YEAR		CAPABILITY	
		1994	1995	1994	1995
BDMECH	**Quantity:**	5	5	1727.5	1922.6
	Personnel:				
	ACONRG	500	500		
	AENLRG	500	500		
	AOFFRG	500	500		
	Equipment:				
	PMICJ	395	375		
	PMLEA	290	350		
	WRM:				
	POL1	350000	750000		
BDARTY	**Quantity:**	1	1	58.5	65
	Personnel:				
	ACONRG	100	100		
	AENLRG	100	100		
	AOFFRG	100	100		
	Equipment:				
	UMMAL	18	20		
	WRM:				
	POL1	7300	8300		
BDARMR	**Quantity:**	1	1	226.6	453.1
	Personnel:				
	ACONRG	100	100		
	AENLRG	100	100		
	AOFFRG	100	100		
	Equipment:				
	PMLEL	50	100		
	WRM:				
	POL1	95000	102000		
BDCS	**Quantity:**	1	1		
	Personnel:				
	ACONRG	100	100		
	AENLRG	100	100		
	AOFFRG	100	100		
	Equipment:				
	NADBA	11	15		
	WRM:				
	POL1	1000	1800		

Table 4.10.B. Case One DRMOM results, continued. If the force possesses multiple units of the same type, those units' personnel, equipment, and WRM are pooled together. For example, there are five Mechanized Brigades (BDMECH). Personnel levels for an each brigade are one-fifth of the reported level. The same logic applies for the units' capability level; individual brigade capability is one-fifth of the reported value.

UNIT	REQUIREMENT	YEAR		CAPABILITY	
		1994	1995	1994	1995
AWING	Quantity:	1	1	440.3	440.3
	Personnel:				
	AOFFRG	59	50		
	Equipment:				
	ADZOP	24	24		
	WRM:				
	POL2	90000	100000		
FLSUB1	Quantity:	1	1	140	120
	Personnel:				
	AENLRG	25	25		
	AOFFRG	69	50		
	Equipment:				
	CAGKI	7	6		
	WRM:				
	POL3	275000	300000		
	TOTAL CAPABILITY:			2592.8	3000.9

Table 4.10.C. The DRMOM Case One results, continued. Total capability represents the sum of capabilities over all units in the force.

Cost Account	1994	1995
RD_BAS	57.0	57.0
PRODAV	0	100000.0
RD_DEV	200.0	215.0
CON_ADM	0	250.0
PAY	24137.5	24319.5
GENOPS	297.0	297.5
BASESPT	478.0	478.0
COMBTNG	68891.0	79245.0
FUEL	0	127200.0
OFFACT	10.0	15.0
INTAGR	25.0	35.0
Total	**94095.5**	**332112.0**

Table 4.11. Case One budget outlay by cost account (1000's of MU). The most significant budget increases result from procurement of new artillery equipment (PRODAV) and an increase in fuel stockpiles.

Case One Reference Levels	
Budget	332112.0
Capability Level	3000.9

Table 4.12. Demonstration Data reference levels (1000's MU). We use these values later for comparison.

b. Case Two: Minimum Budget

The planning horizon for Case Two is one year as well. The DRMOM determines the minimum budget to maintain reference capability level. Force structure can change, if necessary, within the constraints of the model's unit mix requirements. The Ministry of Defense, General Staff, and all headquarters units are fixed at one unit. Case Two optimization generates 7,680 variables, 328 constraints, and 8,107 non-zero's. The reference budget is reduced by 22%. Table 4.13 shows budget allocation. Table 4.14 summarizes the Case Two DRMOM results.

Cost Account	1994	1995
RD_BAS	57.0	57.0
PRODAV	0	50000
RD_DEV	200.0	215.0
CON_ADM	0	250.0
PAY	24137.5	34244.7
GENOPS	297.0	319.5
BASESPT	478.0	494
COMBTNG	68891.0	67359.6
FUEL	0	108425
OFFACT	10.0	15.0
INTAGR	25.0	35.0
Total	**94095.5**	**261414.8**

Table 4.13. Case Two budget outlay by cost account (1000's of MU). Here, the 1995 budget is 22% less than reference.

UNIT	REQUIREMENT	YEAR		CAPABILITY	
		1994	1995	1994	1995
MOD	Quantity:	1	1		
	Personnel:				
	ACONRG	80	100		
	AENLRG	80	100		
	AOFFRG	220	200		
	CCIVRG	150	150		
GS	Quantity:	1	1		
	Personnel:				
	ACONRG	0	300		
	AENLRG	150	90		
	AOFFRG	250	300		
HQAF	Quantity:	1	1		
	Personnel:				
	ACONRG	25	50		
	AOFFRG	119	125		
HQARMY	Quantity:	1	1		
	Personnel:				
	ACONRG	25	50		
	AOFFRG	119	125		
HQNAVY	Quantity:	1	1		
	Personnel:				
	ACONRG	25	50		
	AOFFRG	119	125		
DVMECH	Quantity:	2	1		
	Personnel:				
	ACONRG	140	90		
	AENLRG	70	40		
	AOFFRG	110	50		
CORPS1	Quantity:	1	1		
	Personnel:				
	ACONRG	100	100		
	AENLRG	30	30		
	AOFFRG	30	30		

Table 4.14.A. Case Two minimization results. The DRMOM recommends the disestablishment of one Mechanized Division (DVMECH).

UNIT	REQUIREMENT	YEAR		CAPABILITY	
		1994	1995	1994	1995
BDMECH	Quantity:	5	4.1	1727.5	1581.11
	Personnel:				
	ACONRG	500	411		
	AENLRG	500	411		
	AOFFRG	500	411		
	Equipment:				
	PMICJ	395	308.4		
	PMLEA	290	287.8		
	WRM:				
	POL1	350000	616800		
BDARTY	Quantity:	1	8	58.5	519.7
	Personnel:				
	ACONRG	100	800		
	AENLRG	100	800		
	AOFFRG	100	800		
	Equipment:				
	UMMAL	18	160		
	WRM:				
	POL1	7300	66400		
BDARMR	Quantity:	1	1	226.6	340
	Personnel:				
	ACONRG	100	100		
	AENLRG	100	100		
	AOFFRG	100	100		
	Equipment:				
	PMLEL	50	75		
	WRM:				
	POL1	95000	102000		
BDCS	Quantity:	1	1		
	Personnel:				
	ACONRG	100	100		
	AENLRG	100	100		
	AOFFRG	100	100		
	Equipment:				
	NADBA	11	11		
	POL1	1000	1800		

Table 4.14.B. Case Two results, continued. The DRMOM suggests reducing the number of Mechanized Brigades (BDMECH), and increasing the number of Artillery Brigades (BDARTY) to eight.

UNIT	REQUIREMENT	YEAR		CAPABILITY	
		1994	1995	1994	1995
AWING	Quantity:	1	1	440.3	440.3
	Personnel:				
	AOFFRG	59	50		
	Equipment:				
	ADZOP	24	24		
	WRM:				
	POL2	90000	100000		
FLSUB1	Quantity:	1	1	140	120
	Personnel:				
	AENLRG	25	25		
	AOFFRG	69	50		
	Equipment:				
	CAGKI	7	6		
	WRM:				
	POL3	275000	300000		
TOTAL CAPABILITY:				2592.8	3000.9

Table 4.14.C. Case Two results, continued. The Forces' 1995 capability is equal to the reference level found in Case One, with a 22% decrease in spending.

c. *Case Three: Maximum Capability*

The planning horizon for Case Three is three years, 1994 to 1996. Case Three unit mix requirements are the same as in Case Two. We maximize force capability while remaining within a percentage of the budget found in Case Two. We choose the Case Two budget because it represents the minimum spending necessary to achieve reference capability. For this example, the DRMOM can spend 110% of the budget; representing say, a query for capability increase given a 10% increase in budget allocation. Case Three optimization generates 31,690 variables, 469 constraints, and 32,610 non-zero's. Capability increases 4.1% above reference in 1995, and 11.5% in 1996. Table 4.15 lists the resulting Case Three unit structure, personnel, equipment, and WRM quantities. Table 4.16 lists budget allocation by cost account.

UNIT	REQUIREMENT	YEAR			CAPABILITY		
		1994	1995	1996	1994	1995	1996
MOD	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	80	100	100			
	AENLRG	80	100	100			
	AOFFRG	220	200	200			
	CCIVRG	150	150	150			
GS	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	0	300	300			
	AENLRG	150	90	90			
	AOFFRG	250	300	300			
HQAF	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	25	50	50			
	AOFFRG	119	125	125			
HQARMY	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	25	50	50			
	AOFFRG	119	125	125			
HQNAVY	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	25	50	50			
	AOFFRG	119	125	125			
DVMECH	**Quantity:**	2	2.2	2.2			
	Personnel:						
	ACONRG	140	198	198			
	AENLRG	70	88	88			
	AOFFRG	110	110	110			
CORPS1	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	100	100	100			
	AENLRG	30	30	30			
	AOFFRG	30	30	30			

Table 4.15.A. Case Three results. The DRMOM suggests this force structure based on 110% of the Case Two budget. The 10% budget increase represents, for example, a proposed increase in budget allocation.

UNIT	REQUIREMENT	YEAR			CAPABILITY		
		1994	1995	1996	1994	1995	1996
BDMECH	**Quantity:**	5	4.4	4.4	1727.5	1692.3	1696.8
	Personnel:						
	ACONRG	500	440	441			
	AENLRG	500	440	441			
	AOFFRG	500	440	441			
	Equipment:						
	PMICJ	395	330.1	331			
	PMLEA	290	308.1	309			
	WRM:						
	POL1	350000	660170	661922			
BDARTY	**Quantity:**	1	8	8	58.5	519.7	519.7
	Personnel:						
	ACONRG	100	800	800			
	AENLRG	100	800	800			
	AOFFRG	100	800	800			
	Equipment:						
	UMMAL	18	160	160			
	WRM:						
	POL1	7300	66400	66400			
BDARMR	**Quantity:**	1	1	1	226.6	351.2	475.8
	Personnel:						
	ACONRG	100	100	105			
	AENLRG	100	100	105			
	AOFFRG	100	100	105			
	Equipment:						
	PMLEL	50	78	105			
	WRM:						
	POL1	95000	102000	107100			
BDCS	**Quantity:**	1	1	1			
	Personnel:						
	ACONRG	100	100	100			
	AENLRG	100	100	100			
	AOFFRG	100	100	100			
	Equipment:						
	NADBA	11	15	11			
	WRM:						
	POL1	1000	1800	1800			

Table 4.15.B. Case Three results, continued. The most significant change is the increase of Artillery Brigade units from one to eight.

UNIT	REQUIREMENT	YEAR			CAPABILITY		
		1994	1995	1996	1994	1995	1996
AWING	Quantity:	1	1	1	440.3	440.3	440.3
	Personnel:						
	AOFFRG	59	50	50			
	Equipment:						
	ADZOP	24	24	24			
	WRM:						
	POL2	90000	100000	100000			
FLSUB1	Quantity:	1	1	1.8	140	120	214
	Personnel:						
	AENLRG	25	25	45			
	AOFFRG	69	50	89			
	Equipment:						
	CAGKI	7	6	10.7			
	WRM:						
	POL3	275000	300000	535109			
TOTAL CAPABILITY LEVEL:					2592.81	3123.42	3346.55

Table 4.15.C. Case Three results, continued. The DRMOM suggests the addition of a Submarine Flotilla (FLSUB1).

Cost Account	1994	1995	1996
RD_BAS	57.0	57.0	63
PRODAV	0	55000	55000
RD_DEV	200.0	215.0	225
CON_ADM	0	250.0	0
PAY	24137.5	35828.1	36601.4
GENOPS	297.0	326.7	339.21
BASESPT	478.0	508.4	517.8
COMBTNG	68891.0	70721.8	74095.5
FUEL	0	119267.5	119267.5
OFFACT	10.0	15.0	25
INTAGR	25.0	35.0	0
Total	**94095.5**	**282224.5**	**286134.5**

Table 4.16. Case Three budget outlay by cost account. The DRMOM increases reference force capability nearly 12% with a proposed 10% increase in Case Two spending.

2. The Eastern European Force Data

a. Case One: Actual Force at Authorized Levels

The planning horizon for Case One is one year. As in the Demonstration Data, all personnel, activity, equipment, and WRM levels are fixed at authorized quantities. Case One optimization generates 22,053 variables, 18,720 constraints and 37,776 non-zero's. Table 4.17 lists reference budget and capability levels.

Case One Reference Levels	
Budget	3,257,094.68
Capability Level	11,872.42

Table 4.17. Eastern European Force Data reference levels. We use these values in the later cases.

The reference budget is 61% over the base year budget and the capability increase is only 7%. There is very little capability gain given the increase in budget allocation, due in part, to the procurement costs of new equipment to satisfy authorized levels. We see in later cases that this price versus capability ratio improves with optimization. Table 4.18 provides a summary of the Case One DRMOM budget allocation by cost account.

Cost Account	1995	1996
Base and Facility Support, Fixed	577616.95	577616.95
Base and Facility Support, Variable	19.20	19.20
Construction, Command and Admin.	818.18	818.18
Construction, Electronics and Comm.	1363.64	1363.64
Construction, Medical Facilities	2909.09	2909.09
Construction, Personnel Facilities	2654.09	2654.09
Development and Testing	1180.00	1180.00
Equipment Operations, Fuel	2422.09	4997.12
Equipment Operations, Maintenance	5964.98	5991.85
Equipment Operations, Munitions	537.94	690.26
Equipment Operations, Spares	901.12	1193.50
Other Personnel, Quality of Life	308445.53	331495.98
Pay	962109.45	1041178.69
Procurement, Aircraft		475352.10
Procurement, Armored Vehicles		165105.94
Procurement, Artillery		58311.33
Procurement, Helicopters		54041.53
Procurement, Initial Spares		150100.08
Procurement, Ordinance & Weapons	1279.09	1279.09
Procurement, Other	3164.09	3164.09
Procurement, Support Equipment		225727.75
Procurement, Vehicles	186.36	186.36
Unit Operations, Administration	151706.06	151706.06
Unit Operations, Personnel Support	11.82	11.82
Total	2023289.67	3257094.68

Table 4.18. Eastern European Force Case One results. Here, the major increase in budget allocation is in new equipment procurement.

b. Case Two: Minimum Budget

The planning horizon for Case Two is one year. The DRMOM attempts to reduce budget allocation while maintaining the reference capability found in Case One. Force structure can change, if necessary, within the constraints of the model's unit mix requirements. The Ministry of Defense, General Staff, all headquarters, and all training units are fixed at one unit. Additionally, a subordinate unit can exist only if its parent unit exists. Figure 4.1 summarizes this subordinate unit structure.

Case Two optimization generates 31,049 variables, 19,055 constraints, and 52,684 non-zero's. The DRMOM reduces the reference budget by 31%, only 12% over base year budget allocation. By allowing force structure modification, the DRMOM adds nearly two additional artillery regiments and partial fighter and combat helicopter regiments. Equipment levels increase to fulfill added requirements caused by the unit increases. In all units, the DRMOM chooses to place personnel and activity levels at their authorized levels. Table 4.19 summarizes budget allocation by cost account.

Cost Account	1995	1996
Base and Facility Support, Fixed	577616.95	581634.46
Base and Facility Support, Variable	19.20	19.37
Construction, Command and Admin.	818.18	818.18
Construction, Electronics and Comm.	1363.64	1363.64
Construction, Medical Facilities	2909.09	2909.09
Construction, Personnel Facilities	2654.09	2654.09
Development and Testing	1180.00	1180.00
Equipment Operations, Fuel	2422.09	6066.12
Equipment Operations, Maintenance	5964.98	5944.99
Equipment Operations, Munitions	537.94	721.35
Equipment Operations, Spares	901.12	1293.05
Other Personnel, Quality of Life	308445.53	337195.46
Pay	962109.45	1057654.92
Procurement, Aircraft		
Procurement, Armored Vehicles		2669.15
Procurement, Artillery		59581.14
Procurement, Helicopters		
Procurement, Initial Spares		20750.09
Procurement, Ordinance & Weapons	1279.09	1279.09
Procurement, Other	3164.09	3164.09
Procurement, Support Equipment		20750.10
Procurement, Vehicles	186.36	186.36
Unit Operations, Administration	151706.06	152799.49
Unit Operations, Personnel Support	11.82	11.93
Total	2023289.67	2260646.17

Table 4.19. Eastern European Force Data Case Two results. The DRMOM budget minimization provides reference capability at a 31% reduction in reference cost. Also note that this budget increase is only 12% above the base year level.

c. *Case Three: Maximum Capability*

The planning horizon for Case Three is six years, 1995 to 2000. We maximize force capability while remaining within 110 percent of the budget found in Case Two. This case is significantly larger than previous cases, generating 684,747 variables, 42,388 constraints, and 798,085 non-zero's. With a 10 percent increase in Case Two budget levels, the DRMOM optimization yields significant increases to reference capability. The DRMOM suggests adding thirteen artillery regiments, five mobility units, seven fighter regiments, and increasing the size of a helicopter regiment. Table 4.20 lists yearly capability levels. Table 4.21 provides a summary of Case Three budget allocation by cost account.

Year	Reference	1996	1997	1998	1999	2000
capability	11872.4	12628.0	14485.5	15965.1	16822.0	17356.8
% increase		6.4	22.0	34.5	41.7	46.2

Table 4.20. Case Three yearly capability levels. Year 2000 capability increases nearly 50 percent over reference capability.

Cost Account	1996	1997	1998	1999	2000
Base and Facility Support, Fixed	590329.32	598492.70	605644.38	616012.73	645063.36
Base and Facility Support, Variable	19.75	20.11	20.40	20.85	21.55
Construction, Command and Admin.	818.18	818.18	818.18	818.18	818.18
Construction, Electronics and Comm.	1363.64	1363.64	1363.64	1363.64	1363.64
Construction, Medical Facilities	2909.09	2909.09	2909.09	2909.09	2909.09
Construction, Personnel Facilities	2654.09	2654.09	2654.09	2654.09	2654.09
Development and Testing	1180.00	1180.00	1180.00	1180.00	1180.00
Equipment Operations, Fuel	10180.87	5317.63	4741.14	5561.31	4467.18
Equipment Operations, Maintenance	5963.98	5989.38	6009.74	6037.35	6055.28
Equipment Operations, Munitions	868.46	648.26	637.07	675.12	639.47
Equipment Operations, Spares	1722.00	1096.68	1056.22	1193.11	2819.23
Other Personnel, Quality of Life	333332.08	347545.46	258664.85	359990.50	358843.20
Pay	1049177.83	1090433.18	1122474.91	1130740.41	1124013.01
Procurement, Armored Vehicles	2623.70	7395.41	7353.40	2348.23	27087.89
Procurement, Artillery	192386.57	151505.57	120573.29	111287.11	69179.79
Procurement, Initial Spares	65003.43	52967.00	42642.22	37878.45	32089.23
Procurement, Ordinance & Weapons	1279.09	1279.09	1279.09	1279.09	1279.09
Procurement, Other	3164.09	3164.09	3164.09	3164.09	3164.09
Procurement, Support Equipment	65003.43	52966.99	42642.22	37878.45	32089.23
Procurement, Vehicles	186.36	186.36	186.36	186.36	186.36
Unit Operations, Administration	155177.27	157410.09	159328.44	162164.35	169419.14
Unit Operations, Personnel Support	12.17	12.40	12.58	12.87	13.28
TOTAL:	2485355.42	2485355.39	2485355.39	2485355.39	2485355.39

Table 4.21. The DRMOM Eastern European Force Data Case Three results. Budget is at 110% of case two budget level. The Force realizes a nearly 50% gain over reference capability over the six year planning horizon.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Decision makers can apply the DRMOM to develop modernization strategies for Eastern European Forces. When accompanied by an electronic spreadsheet for dealing with the DRMM data in a convenient fashion, the model is adaptable and responsive, providing users optimal solutions in under two minutes. The model either minimizes the budget while maintaining desired capability, or maximizes capability using available or projected funding levels.

B. LIMITATIONS

The best set of force modernization alternatives can be selected optimally provided accurate data. The DRMOM currently requires more data than is available, inhibiting the recommendation of specific modernization alternatives. The DRMM data does not include available budget levels, personnel hiring or dismissal costs, equipment disposal costs, upper or lower bounds on the number or type of units, or the actual activity levels of existing units. Furthermore, to accurately assess modernization alternatives, unit procurement and decommissioning costs must be provided.

C. FUTURE RESEARCH

A complete decision support system for the optimization of Eastern European forces will require additional work. The optimization model here captures just enough realism at a yearly level of detail to support the optimization demonstration.

To improve model performance, unit capability and cost data must be aggregated. Presently, each unit in the DRMOM is unique regarding its name, personnel, equipment, and WRM levels. By incorporating the units into a smaller set of generalized unit types, and providing estimated cost and capability data based on these types, both model speed and capacity can be greatly improved.

To be an effective decision aid, any model must be flexible and user friendly. Presently, the DRMOM model operates in the MS-DOS environment, while the DRMM operates in Windows. Implementing the DRMOM with a Windows based optimization program, linked to the DRMM through a graphical user interface, will significantly ease it's use. Furthermore, linking both models to a database management system capable of recording and comparing multiple modernization alternatives would provide decision makers with a more effective tool.

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